The CAPTAIN program

Kevin Yarritu

LANL

August 27, 2013

CAPTAIN detector

- CAPTAIN: Cryogenic Apparatus for Precision Test of Argon Interactions with Neutrinos
- funded by LANL LDRD (Laboratory Directed Research and Development)
- 5-ton liquid argon detector being built at Los Alamos
- Develop laser calibration system
- Perform physics studies using the neutron beam at Los Alamos. In addition, may also in the NuMi beamline or SNS (Spallation Neutron Source)

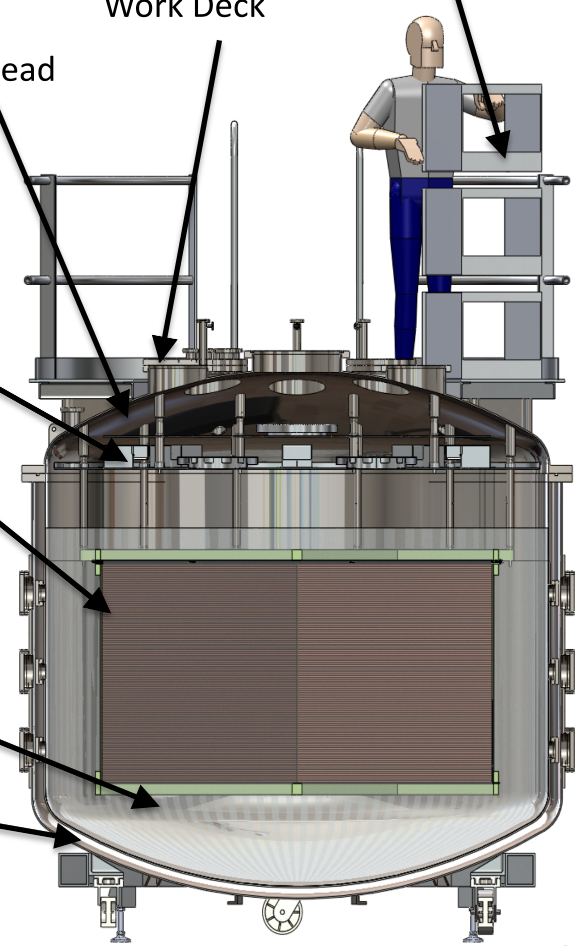
CAPTAIN detector

- Cryostat
  - Capacity: about 7700 L
  - all instrumentation done through top head

- TPC
  - Hexagonal prism, vertical upward drift of 1m
  - 500 V/cm drift field
  - 667 wires/plane (3 planes)
  - ~2k channels with 3 mm wire spacing

- Laser calibration system

- Photon detection system



and there is a mini-Captain!

- Cryostat
  - Capacity: ~1700 L
  - Diameter: 1.5 m
  - Height: 1.64 m

- TPC
  - 3 planes
  - 1000 wires
  - 32 cm drift length

- allows for operational experience

CAPTAIN Collaboration

I. Stancu
University of Alabama

Z. Djurcic
Argonne National Laboratory

V. Gehman, R. Kadel, C. Tull
Lawrence Berkeley National Laboratory

H. Berns, C. Grant, E. Pantic, R. Svoboda, M. Szydagis
University of California, Davis

M. Smy
University of California, Irvine

D. Cline, K. Lee, H. Wang, A. Termourian
University of California, Los Angeles

O. Prokofiev
Fermi National Accelerator Laboratory

J. Danielson, S. Elliot, G. Garvey, E. Guardincerri, D. Lee,
Q. Liu, W. Louis, C. Mauger, J. Medina, G. Mills,
J. Mirabal, J. Ramsay, K. Rielage, G. Sinnis, W. Sondheim,
C. Taylor, R. Van de Water, A. Yarritu
Los Alamos National Laboratory

S. Mufson
Indiana University

T. Kutter, W. Metcalf, M. Tzanov
Louisiana State University

C. McGrew, C. Yanagisawa
State University of New York at Stony Brooke

C. Zhang
University of South Dakota

R. McTaggart
South Dakota State University

Physics Goals for CAPTAIN

- In the current scope of the LDRD

  - build liquid argon TPC

  - reconstruct cosmic ray muons and develop and run calibration system

- Post LDRD goals

  Neutron beam run at LANL

  - study spallation events
  - study backgrounds for surface running of LBNE
  - neutrino energy reconstruction
  - beam-induced background for the near detector

Physics Goals for CAPTAIN

- Post LDRD goals

  NuMI at Fermilab in medium energy tune

  - explore resonance and DIS regions

  SNS running (supernovae energies)

  - study neutrino-argon cross sections
  - study de-excitation gammas from nuclear decay

Physics goals which are part of LDRD

- Studies for future ~~CP~~ experiments (e.g. LBNE)

  - The LBNE far detector will not be magnetized, cannot do μ^+/μ^- separation by track curvature

  - Approximately 75% of μ^- are captured by the argon nuclei

    gamma and neutron cascade

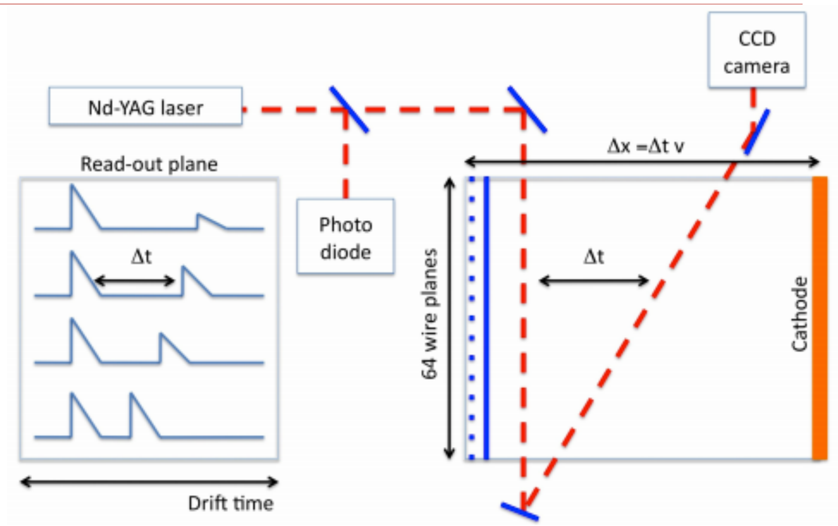
  - All μ^+ will decay

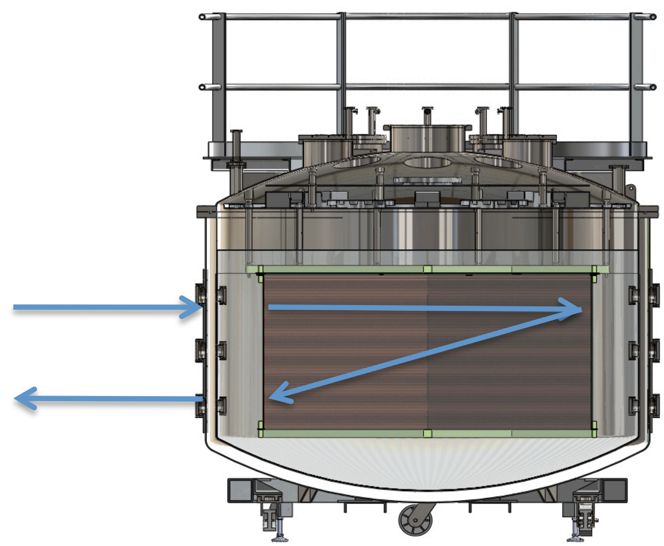
  - If we can identify the captures with high purity and with reasonable and quantifiable efficiency, we can do neutrino/anti-neutrino-separation

  - This allows CP studies to be performed
- Supernova-related studies
  - spallation backgrounds
  - low energy particle identification, e.g. β/γ
- Calibration system development – laser calibration

Laser Calibration System

- Measure drift velocity
  - high muon rate leads to space charge buildup
  - potential hardward problems
- Measure electron lifetime
  - current LBNE spec. T > 0.85ms
  - at 1.5ms drift time ~ 20% of the electrons survive
  - need lifetime of ~1% to achieve 2% resolution

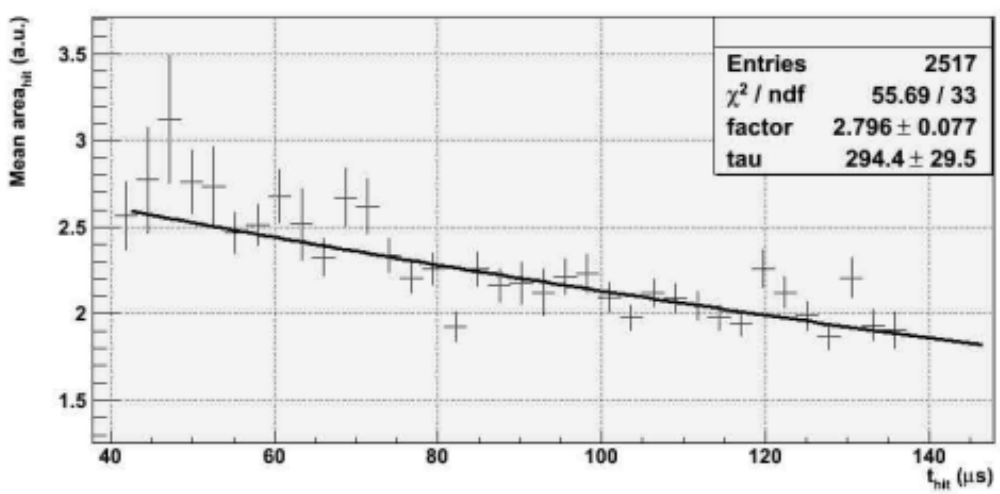




Laser Calibration

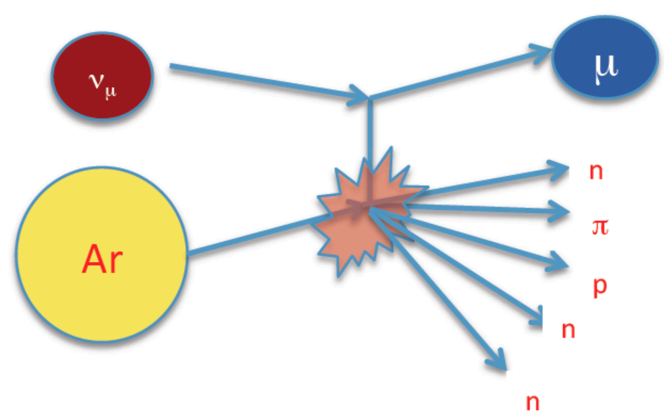
- Ionization potential of LAr is 13.78 eV
- Nd-YA laser
  - Quantel Laser 90 mJ/pulse
- Based on recent work by the University of Bern (B. Rossi et al.)

$$Q_{meas} = Q_{dep}\,\mathrm{Re}^{-t_{drift}/\tau}$$



Neutron Running at LANSCE

- Characterize neutron interactions to understand energy carried by neutrons in neutrino interactions with argon
- measure response of LArTPC to neutrons
  - multi-particle events in high-energy regime
  - characterize reconstruction efficiency of these events
- measure "cosmogenic" production of radioactive isotopes
  - validate simulations of spallation that provide a background for neutrino interactions
- want neutron beam with cosmic-ray neutron spectrum

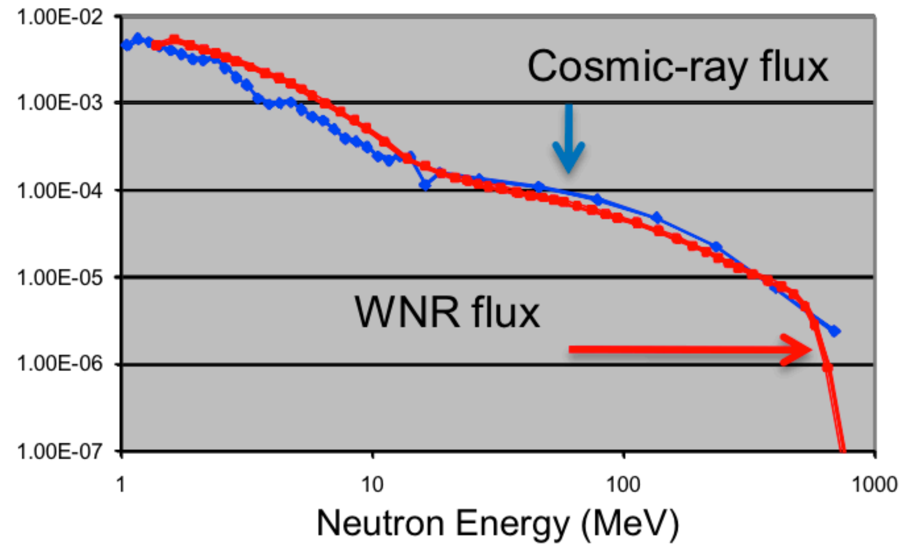


Neutron Running at LANSCE

- WNR at LANL provides a neutron beam with energy spectrum similar to cosmic-ray neutron spectrum

- measure production of backgrounds to low energy neutrino events
  - specifically ν_e appearance

- neutron energy is measured by using time-of-flight
  - energy resolution of ~10% at 500 MeV



Timeline….

- it changes
- we now have a new detector called Bacon.

Spallation Neutron Source (SNS)

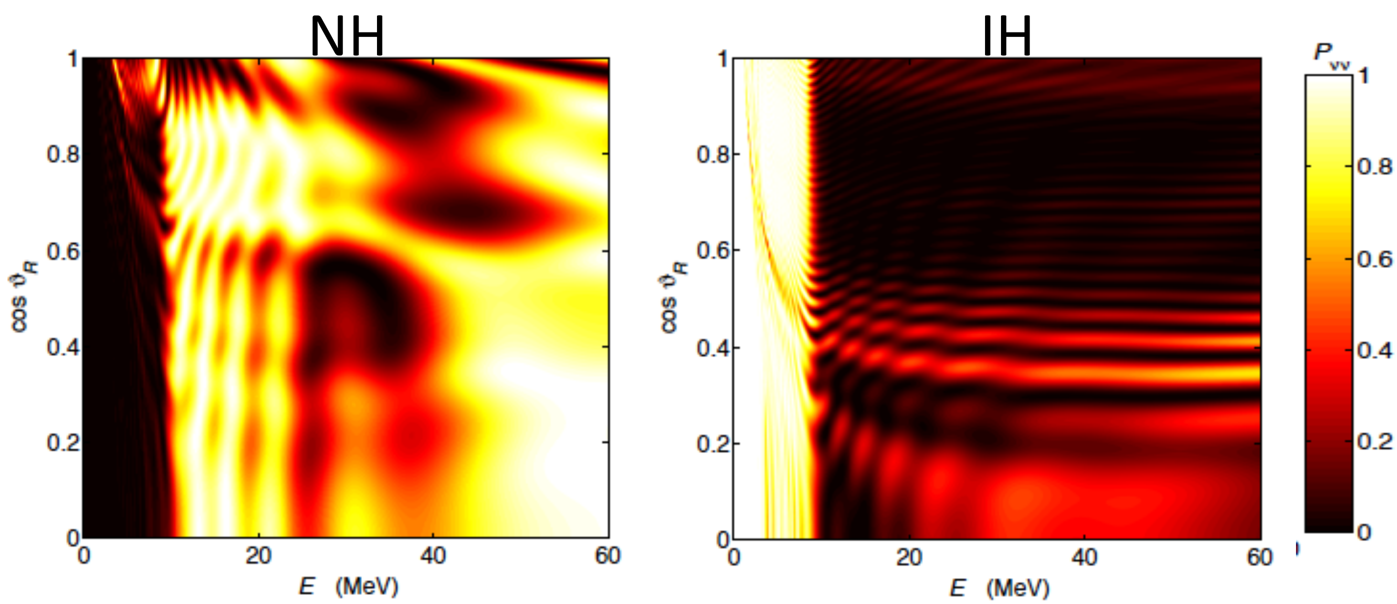
- four reactions that are used to detect supernova events (K. Scholberg)

Reaction	Events/10kT
$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	~700
$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$	~60
$\nu_x + e^- \rightarrow \nu_x + e^-$	~90
$\nu_x + {}^{40}\mathrm{Ar} \rightarrow \nu_x + {}^{40}\mathrm{Ar}^*$	~85 (A. Hayes)

- Elastic scattering preserves direction of neutrino
- reactions identified by de-excitation gammas

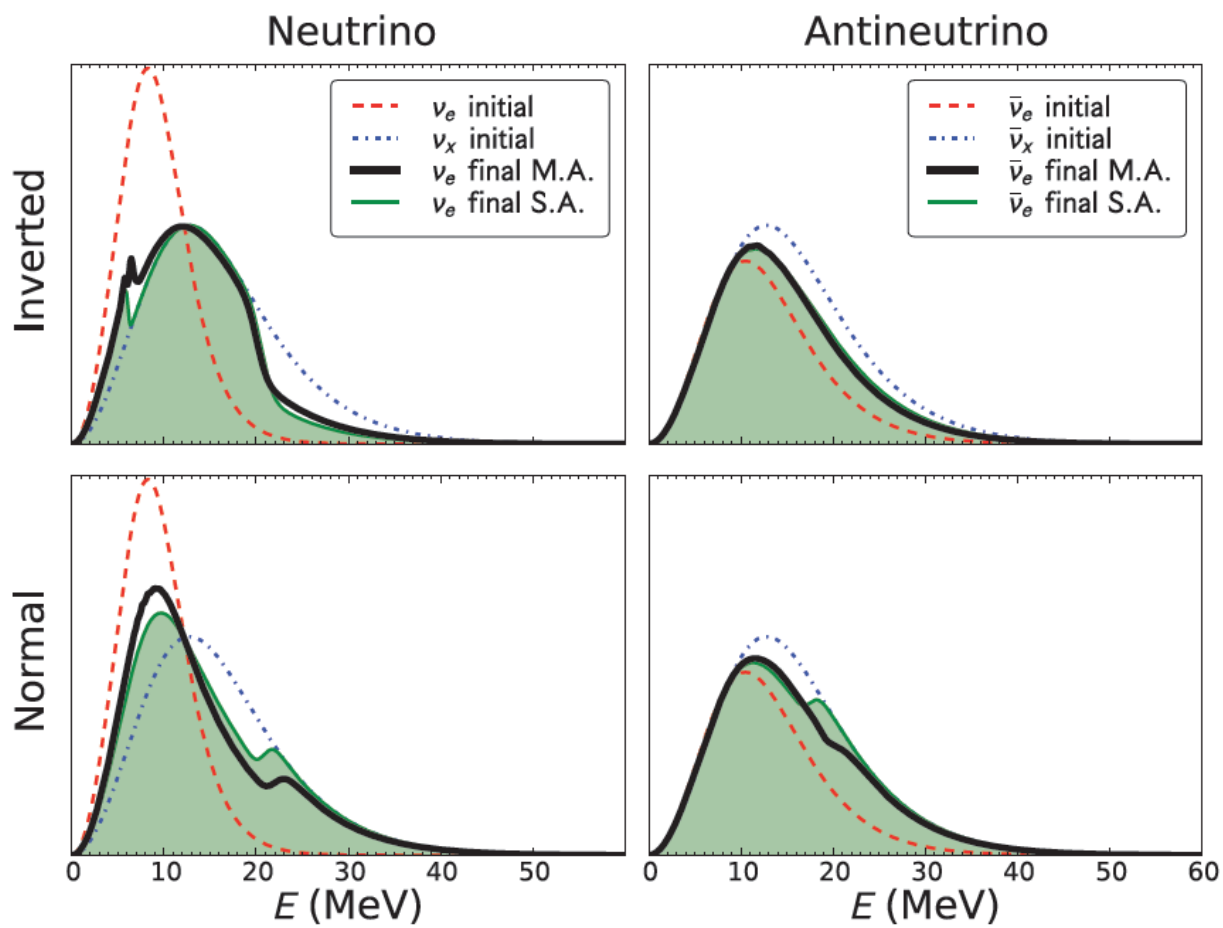
Spallation Neutron Source

- collective oscillations result in spectral swap
  - NH: ν_x flavor change below 10 MeV
  - IH: ν_x flavor change above 10 MeV



[3] H. Duan, G. M. Fuller, and Y. Quan Ann. Rev. Nucl. Part. Sci. 60 (2010) 569.

Spallation Neutron Source (energy spectra)

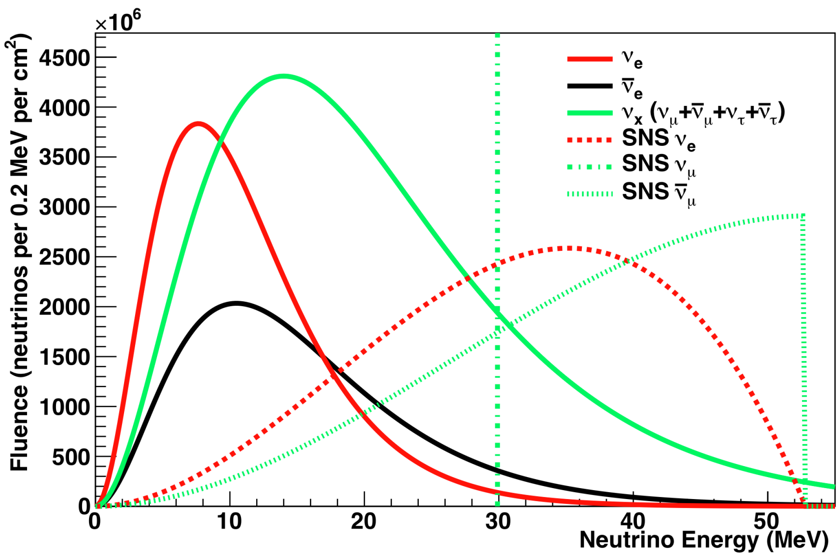


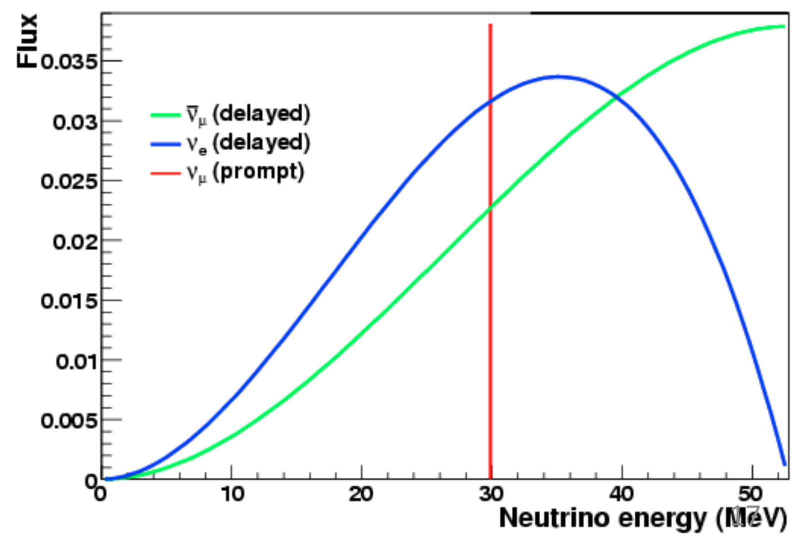
H. Duan and A. Friedland, Xiv:1006.2359v1

Spallation Neutron Source

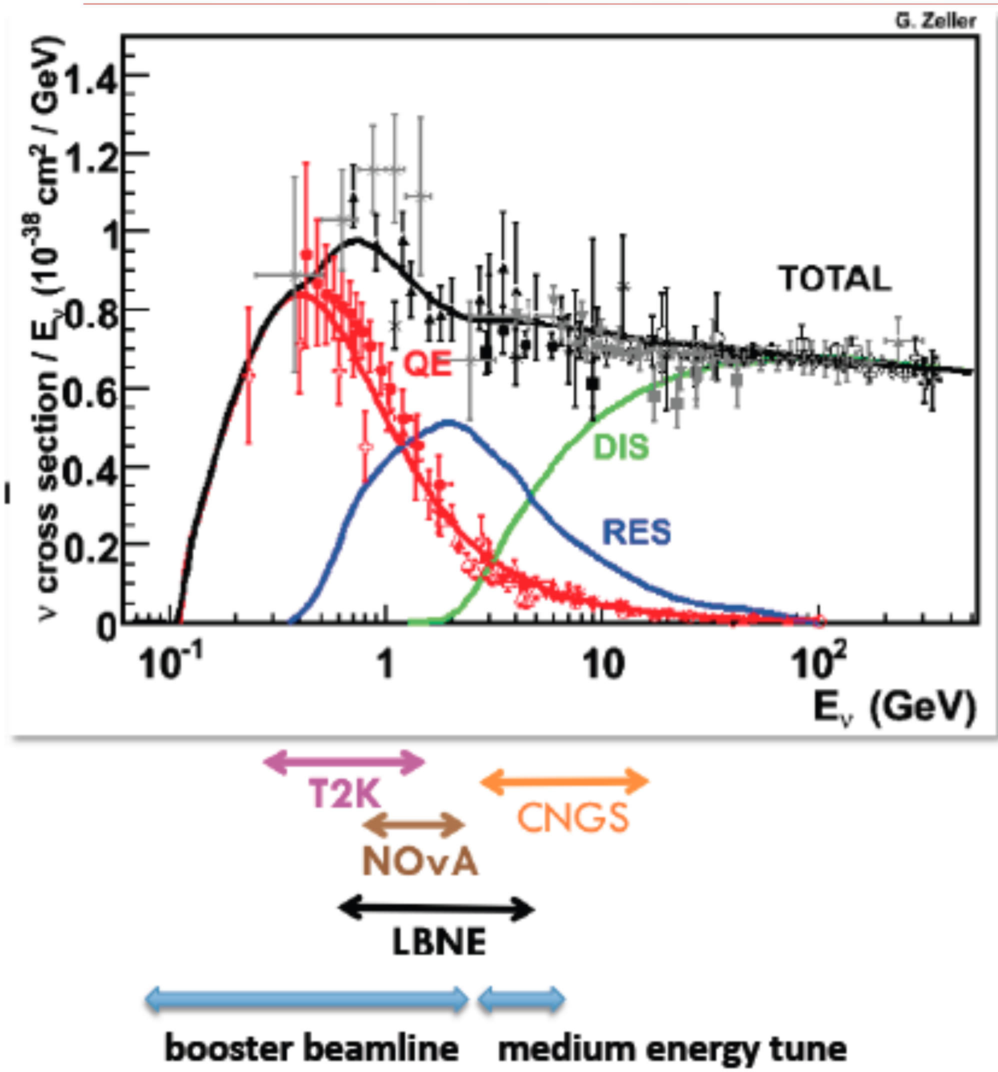
- stopped pion source
- At 50m from target there is a supernovae a day
- measure cross sections
- running on surface

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\downarrow$$
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$



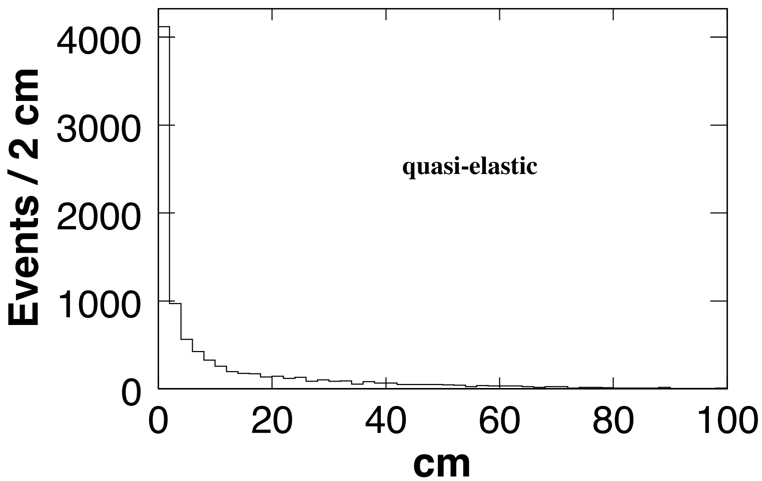


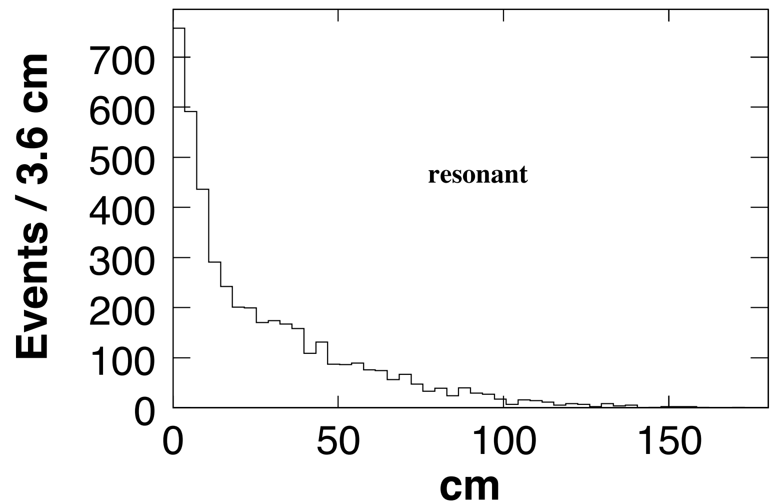
Running in NuMi Beamline

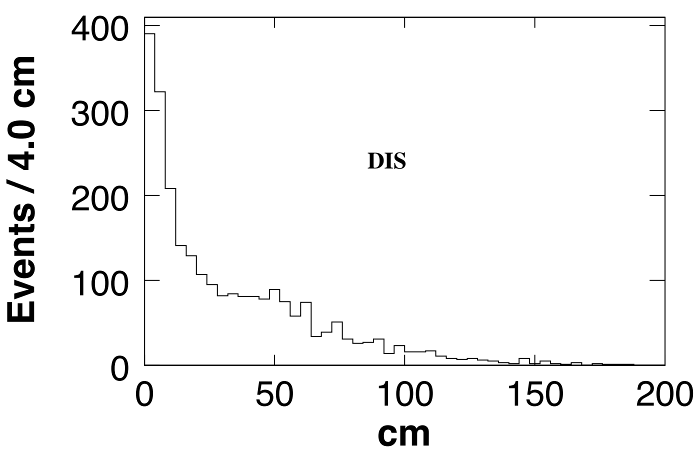


- run CAPTAIN in on-axis NuMi beam
- energy regime complements Micrboone
  - LBNE region covered by Micrboone + medium energy tune
- make measurements of cross sections for the resonance region
- 10% containment
  - includes all particles but the primary lepton and neutrons
  - 370,000 contained CC events per year (4×10^{20} POT per year)

NuMi Beamline (contained events)







Shown is the distance from the vertex to the endpoint of the longest track in the event for contained events

Conclusions

- CAPTAIN can make significant contributions to neutron and neutrino cross sections
- Laser calibration has been already tested and developed
- SNS running would shed light on neutrino-argon cross sections at low energy

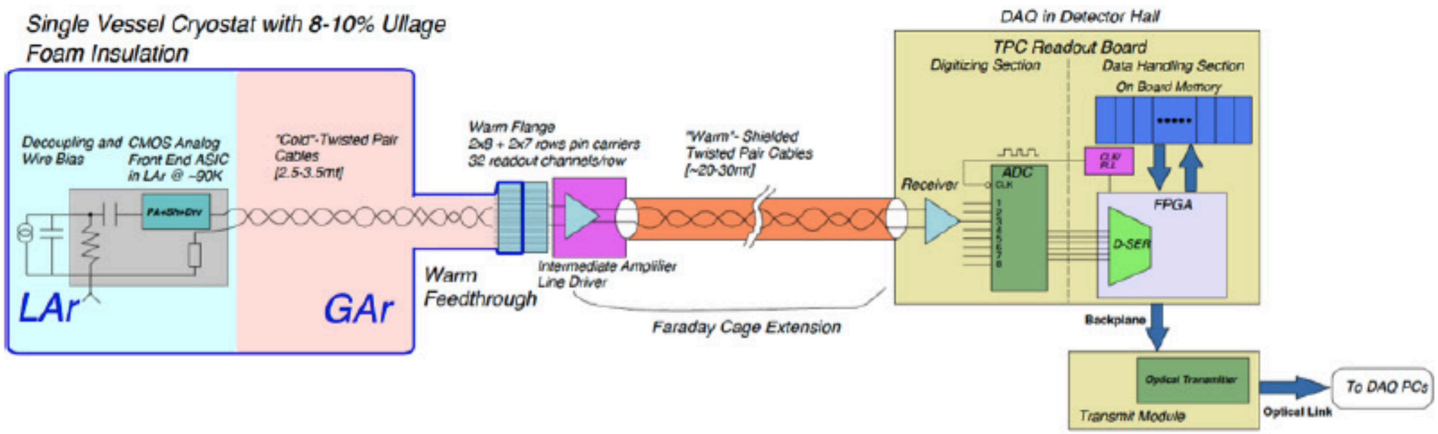
backup

Laser properties

Table 1. 4^{th} harmonic UV laser specifications.

wavelenght (nm)	max repetition rate (Hz)	max energy (mJ)
266	10	82
pulse width (ns)	rod diameter (mm)	divergence (mrad)
4-6	6	0.6

DAQ



Single Vessel Cryostat with 8-10% Ullage
Foam Insulation
Decoupling and Wire Bias
CMOS Analog Front End ASIC in LAr @ ~90K
"Cold"-Twisted Pair Cables [2.5-3.5m]
LAr
GAr
Warm Flange
2x8 + 2x7 rows pin carriers
32 readout channels/row
Warm Feedthrough
Intermediate Amplifier Line Driver
"Warm"- Shielded Twisted Pair Cables [~20-30m]
Faraday Cage Extension
DAQ in Detector Hall
TPC Readout Board
Digitizing Section
Data Handling Section
On Board Memory
Receiver
ADC
FPGA
D-SER
Backplane
Optical Transmitter
Transmit Module
Optical Link
To DAQ PCs

Calibration system: motivations

- Due to recombination in LAr only a fraction of the charge produced from ionization survives after drifting a time τ_{drift}

$$Q_{meas} = Q_{dep} \mathrm{R} e^{-t_{drift}/\tau} \longleftarrow R = \frac{A}{1+(k/\Sigma)\frac{dE}{dx}}$$

  - τ = 1 ms, Σ = 500V/cm
  - drift speed at 500V/cm is 1.6mm/μs
  - For 2.3m drift distance only 24% of the charge survives
  - 2% energy calibration requires ~1% uncertainty in τ_{drift}
- Due to the long drift time of ions the space charge effects are not negligible (-17 to 8V/cm in X and -5 to 12V/cm in Y)
  - $v_{drift} \cong$ 8mm/s -> $\tau_{drift} \cong$ 5min from anode to cathode
  - Changes in drift velocities will “compress” tracks distorting the measured dQ/dx (4% effect)

Isotopes of liquid argon

Isotope	Half-life
^{39}Ar	269 years
^{42}Ar	32.9 years
^{37}Ar	35.04 days
^{41}Ar	109.6 minutes